Scattering from Heterogeneous Elastic Layered Sea Beds

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LONG-TERM GOALS

The long term scientific objective of this research is to improve our understanding the physics and mechanisms of acoustic bottom interaction and reverberation, including acoustic penetration, propagation, attenuation and scattering in elastic heterogeneous layered sea beds.

OBJECTIVES

The specific goal of this research is to develop a model of acoustic scattering due to volume heterogeneity consistent with existing propagation models in elastic layered sea beds and therefore to provide a self-consistent theoretical basis for improving and upgrading current bottom interaction codes (such as GABIM). At this first stage of research, the model should be capable of explaining backscattering data obtained for the stratified (layered) SAX04 sediment, and be consistent with results of the sediment particle analysis of the samples collected during the SAX04 experiment.

APPROACH

In most practical cases, acoustic bottom interaction process can be described in terms of two major measurable acoustic characteristics: the bottom reflection loss and the bottom scattering strength. At present, GABIM (Geophysical Acoustic Bottom Interaction Model [1]) developed at APL-UW represents the most general code used for predicting and analysis of these characteristics for a wide variety of sea bed types.

Due to general sedimentation and stratification processes, bottom geoacoustic parameters are usually functions of depth (this way these parameters are normally documented in various existing sediment databases and models [2]). The main motivating idea and ultimate goal for development of GABIM is to provide practical possibility for modeling and prediction concurrently both reflection and scattering from seafloors with *arbitrary* stratification, so that these depth-dependent functions taken from the sediment data bases could be directly used for such predictions.

Development of the GABIM code is based on published results of basic research. However, the existing theoretical basis, presented in published literature, has not yet been developed adequately, and is unable yet to fulfill above-mentioned goals of GABIM. Particularly for this reason, GABIM has several drawbacks which significantly limit its practical capabilities. The main goal of this

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research is to develop an adequate theoretical basis for direct improving of GABIM. This project is a natural extension of the PI's previous research. Generally, the idea of this project is to build on previous work: the elastic scattering model described in [3-5], a perturbation approach developed for scattering from continuous heterogeneity in layered fluid media [6-8], and discrete scattering work started in [9,10].

There are two major mechanisms of bottom scattering, volume and roughness, which are due to the interface roughness and the volume heterogeneity of the sea bed medium. Contributions of both mechanisms are generally important and are addressed in GABIM only to limited extent [11]. However, given time frames for this project, the research is focused on study of only the volume scattering mechanism. This mechanism can be due to two different types of seabed heterogeneity: continuous, smooth spatial fluctuations of acoustic parameters of the sediment matrix, and discrete, such as relatively large shells, rocks, and other "inclusions" supported by the sediment matrix.

Given different environmental conditions, frequencies and angles of scattering, relative contributions of scattering mechanisms can be also different. For example, in the SAX99 situation, the contribution of the volume continuous heterogeneity to the observed seabed backscattering was shown to be insignificant [12]. For the sediment rough surface scattering, first conclusion was that it is the dominant mechanism in a wide frequency range, roughly 20 kHz to 200 kHz. In later work, however, it was shown that the contribution of another volume mechanism in SAX99 sediment, discrete heterogeneity, also can be important, particularly at frequencies above 50 kHz [9,10].

Acoustic backscattering from the sediments at SAX04 was quite different from SAX99 [13]. This was result of substantially different environmental conditions caused by known weather events preceding and during SAX04, and, resulting from these events, more complex structure of the SAX04 sediment [14]. In particular, an important complication is appearance of a thin but distinctive mud layer covering a sand basement. The thickness of the mud layer varied from a few mm (forming a thin transition layer between water and sand) to about 5 cm (filling depressions in the sand rough surface). This, in particular, resulted in more flat surface of the sediment in comparison with SAX99.

The roughness spectra were measured on both boundaries of the mud layer and it was shown that the roughness scatter itself can provide only insignificant contribution to the observed scattering level [13]. Therefore, the SAX04 acoustic data analysis (unlike SAX99) was narrowed down to scattering mechanisms caused by volume heterogeneity of the sediment. Possible effects of volume scattering in the SAX04 sediment were examined in [13], where however only contribution of continuous heterogeneity was considered, using a model similar to GABIM. The contribution of another mechanism due to discrete heterogeneity in the SAX04 environment has not been examined.

And the current version of GABIM can not help, because its volume scattering kernel does not include the possible contribution of discrete scatterers. At the first stage of this research, we are developing a model which should be capable of fulfilling this gap. Another practical goal is to apply this model to analysis of backscattering data obtained for the stratified (layered) SAX04 sediment, consistently with results of the sediment particle analysis of the samples collected during the SAX04 experiment.

According to results of environmental analysis, the SAX04 sediment was characterized as a stratified mixture of medium quartz sand and mud, with presence of a small volume portion of carbonate shells and shell fragments [14,15]. Therefore, shells can be considered as inclusions

supported by the stratified mud-sand matrix. An approach to description of scattering from sediments with spherical inclusions in a statistically uniform and homogeneous (non-stratified) matrix was developed and applied to the SAX99 data analysis in [9,10]. However, to be applicable to the SAX04 environment, this approach requires modifications related with two major complications. First modification has to take into account the above-mentioned mud-to-sand stratification of the SAX04 sediment. Second modification is to account for essentially non-spherical shapes of discrete scatterers in the sediment, such as shells and shell fragments. The above-mentioned tasks, including the SAX04 data analysis, modeling, and model/data comparisons, have been accomplished.

WORK COMPLETED

An overview of published theoretical models of scattering from layered and elastic seafloors was performed [11] to describe the up-to-date theoretical base of GABIM and how much of it has been already implemented in the current version of GABIM [1].

A part of modeling effort has been completed, to provide a theoretical approach to discrete scattering in stratified sediments. A method has been developed, somewhat combining approaches used in [9,10] and [3,11], and then accounting for non-spherical shape of scatterers. The method is described in detail in [16,17], and applied to analysis of the SAX04 seabed scattering data obtained by K. Williams [13].

RESULTS

The main results of the project at this stage are described in two papers published this year [11,16] and one submitted for publication [17].

1) An overview of geoacoustic bottom interaction models [11].

An overview of published theoretical models of scattering from layered and elastic seafloors was performed and discussed, as part of [11]. This work has clarified and specified the up-to-date theoretical base of GABIM. This also allowed listing limitations of GABIM and outlining the ways of eliminating these limitations. The main limitations and required improvements are as follows:

-In the current GABIM terminology [11], elastic effects are involved to correct only the contribution of the sediment basement, either covered or not by fluid sediment. Scattering from either rough internal boundaries or volume heterogeneities of a fully elastic layered bottom has not yet been presented in the literature.

-Regarding volume scattering, an improvement to GABIM would be include also the kernel for the case of discrete scatterers, such as shells and nodules (or rocks), or bubbles in the sediment.

-Another improvement would be to remove the windowing approximation used in the anisotropic volume scattering approach [11]. This would require a numerical integration and, having generally only a modest effect on backscattering predictions, will significantly alter bistatic predictions near the specular direction.

-Published volume and roughness scattering work is based mostly on small perturbation approaches. This results in some limitations for the validity of bottom scatter predictions by GABIM, particularly near the specular direction (vertical incidence in the case of backscatter). The current version of GABIM addresses this issue only to a limited degree and only for roughness scattering by using the Kirchhoff approximation near vertical incidence.

-The integral used in the Kirchhoff approximation is also needed for the more accurate small slope approximation, which however can be used only in the case of non-stratified bottom. For now, no version of the small slope approximation has yet been developed applicable to layered seafloors. For more discussion on the above, see [11] and Refs therein.

2) *Scattering from Inclusions in Marine Sediments: SAX04 Data/Model Comparisons* [16,17].

The role of discrete scattering in marine sediments is evaluated based on acoustic and environmental measurements made during the shallow water sediment acoustics experiment, SAX04, and shown to be significant. The sediment at SAX04 site was characterized as a stratified mixture of medium quartz sand and mud (the sediment matrix), with presence of a small volume portion of carbonate shells and shell fragments (inclusions). The scattering model, developed in this paper, considers inclusions as sparse relatively large (in comparison to the mean grain size) randomly oriented particles of irregular shape. The size and shape of a non-spherical inclusion are defined through its volume and surface area, and their statistical distributions, critical inputs to the model of scattering, are obtained using a novel approach to the particle characterization of coarse content, applied to the SAX04 sediment samples [15].

The results of the SAX04 scattering data/model comparisons are presented, discussed, and demonstrated that presence of shell-inclusions in the sand/mud environment may have a significant impact on the seabed reverberation. In particular, it provides an explanation of both frequency and angular dependencies of the SAX04 bottom backscattering strength in a wide range of grazing angles (15 to 50 degrees) and frequencies (30 to 200 kHz). For explaining the SAX04 data at higher frequencies, 200 to 500 kHz, another inclusion scattering mechanism is suggested, accounting for presence of coarse sand particles in a top sediment layer of mud, which also was noticed as typical for the SAX04 sand-mud environment.

IMPACT/APPLICATIONS

This research is to develop an adequate theoretical basis for direct improving of GABIM, Geophysical Acoustic Bottom Interaction Model, the most general code used for predicting and analysis of the bottom scattering strength and reflection loss for a wide variety of sea bed types. GABIM is planned for submission to OAML (Oceanographic and Atmospheric Master Library) and has been already widely used in the applied research and development community. In particular, it is one of the primary tools used in the Ocean Bottom Characterization Initiative (OBCI). The model of discrete scattering from inclusions in arbitrary stratified sediment developed in this research can be applied to upgrade GABIM.

This work has demonstrated that the sediment coarse content, corresponding to particles with sizes noticeably greater than the mean grain size, or the sediment inclusions (such as relatively large shells and rocks), has a significant effect on seabed scattering properties. This can have an impact on the very principles of development of the sediment data bases for geoacoustic characterization of the seafloor, which is the main focus of several Navy-sponsored programs (including OBCI).

RELATED PROJECTS

This work is closely connected to other projects supported by the ONR-OA SAX04 program and strengthens its modeling component. This project is built on results of previous work funded by ONR-OA [4,5,8-10]. It is closely related with ongoing work to upgrade GABIM (Geophysical

Acoustic Bottom Interaction Model [11]) developed at APL-UW, which is widely used in the applied research and development community.

PUBLICATIONS

D.R. Jackson, R.I. Odom, M.L. Boyd, and A.N. Ivakin (2010), "A geoacoustic bottom interaction model (GABIM)", *J.Oceanic Eng.*, **35**(3), 603-617. [published, referred]

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